LT-4203 Parallel Plate Test Fixture
Specifications and User's Guide

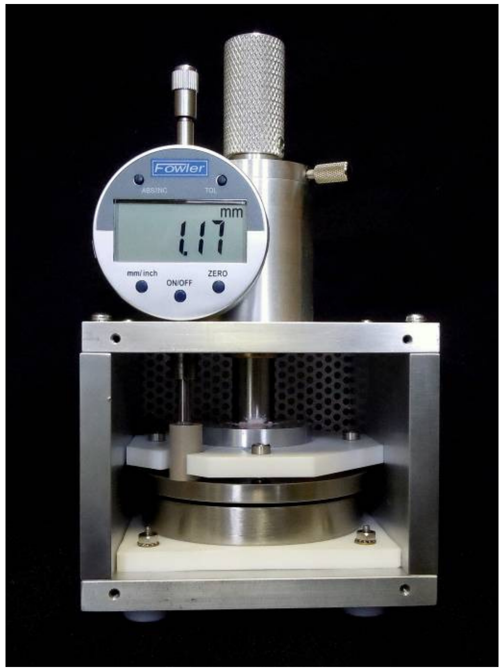

Figure 1
LT-4203 Parallel Plate Test Fixture

DESCRIPTION

The LT-4203 Parallel Plate Test Fixture is designed for measuring the AC loss characteristics and permittivity of solid laminates and panels per ASTM Standard D150-98, and implements the guarded electrode (three terminal) measurement preferred as the referee method.

The standard sense electrode is 6.0 cm in diameter and the electrode separation may be adjusted to accommodate various sample thicknesses. A removable micrometer head permits measurement of electrode separation before testing. The 1.0 cm wide guard electrode eliminates fringing electric fields around the sense electrode for accurate calculation of test cell capacitance. Both electrodes are surrounded by a grounded frame which acts as a Faraday cage to reduce pickup of external electrical noise.

Maximum operating temperature of the LT-4203 is 150 °C, allowing measurement of dielectric properties at elevated temperatures. Modification of the LT-4203 for operation up to 200 °C is available upon request.

The LT-4203 Parallel Plate Test Fixture may be used with either the Lambient Technologies LT-451 Dielectric Cure Monitor or generic LCR meters. When used with the LT-4203, the LT-451 can test samples with thicknesses between 0.025 cm and 0.50 cm with optimum accuracy.

SPECIFICATIONS

Dimensions:

Overall (length x width x height)	:	11.2 cm x 12.4 cm x 20.3 cm (4.4” x 4.9” x 8.0”)
Diameter, excitation electrode	:	8.00 cm
Diameter, sense electrode	:	6.00 cm (Area = 28.27 cm^2)
Width, guard electrode	:	1.00 cm

Composition:

Electrodes	:	Stainless steel
Insulator	:	Teflon
Body	:	Aluminum

Operational:

Temperature, maximum	:	150 °C (302 °F)*

*Modification for operation to 200 °C (392 °F) available upon request

Connections:

Excitation electrode	:	BNC**
Sense electrode	:	Triax**

**Electrode connections may be modified upon request

Recommended sample dimensions	:	8.0 cm x 8.0 cm to 9.0 cm x 9.0 cm (maximum)
Optimum sample thickness	:	0.025 cm to 0.50 cm

Test Fixture Parameters:

A/D ratio	:	28.27 cm^2 / sample thickness in cm
Base (parasitic) capacitance	:	~15 pF (actual value may vary)

Micrometer Attachment	:	Removable for use at elevated temperatures
Accuracy	:	0.03 mm (0.001”)
Resolution	:	0.01 mm (0.0005”)

Features—

- On/Off switch
- Adjustable ZERO reference
- Absolute/Incremental readings
- Direct mm-in conversion

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PARTS LIST FOR THE LT-4203 PARALLEL PLATE TEST FIXTURE

1. Carefully remove the LT-4203 and its accessories from the shipping carton.
2. Check that all parts and accessories on the Packing List are included. Contents are subject to change without notice.

The LT-4203 standard package has the following items:

Qty	Description
1	LT-4203 Parallel Plate Test Fixture
1	Removable micrometer (electronic indicator)
1	Transition box
1	BNC cable (black)
1	Triax cable (yellow)
1	LT-451 extension cable
1	3/32" Allen wrench
1	User's Manual/Software manual on CD-ROM (English version)*

3. Check that all options on the Packing List are included.
4. Please report any missing items to your local Lambient Technologies representative immediately.

*Contact local distributor for availability of documentation in other languages

ASSEMBLING THE LT-4203 PARALLEL PLATE TEST FIXTURE

Figure 2 below shows the LT-4203 Parallel Plate Test Fixture and knobs which adjust the plate separation and lock the plate position.

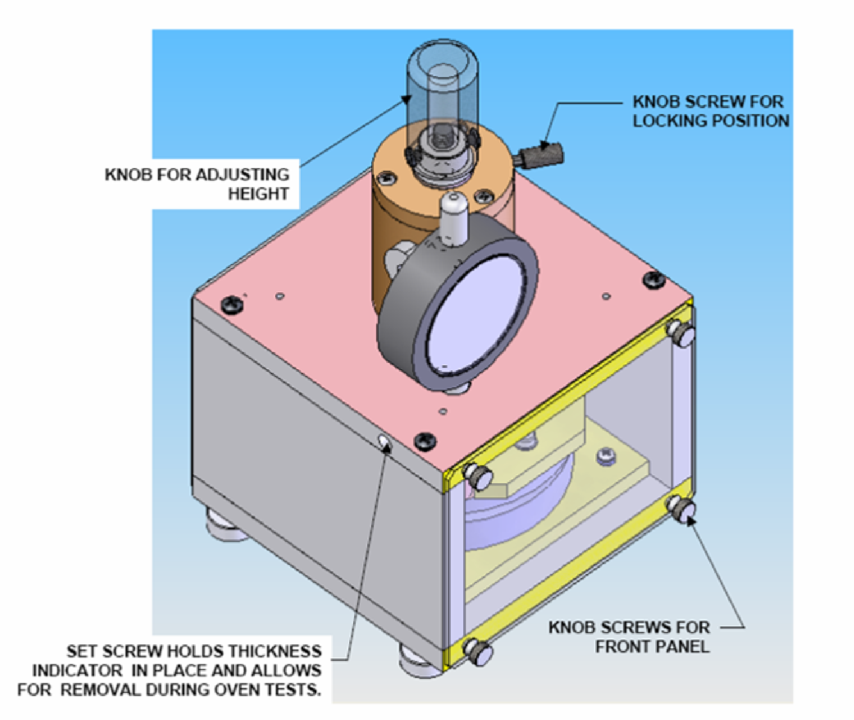

Figure 2
LT-4203 Parallel Plate Test Fixture

The digital indicator shown in Figure 3 is included for determining plate separation, but must be mounted by the user.

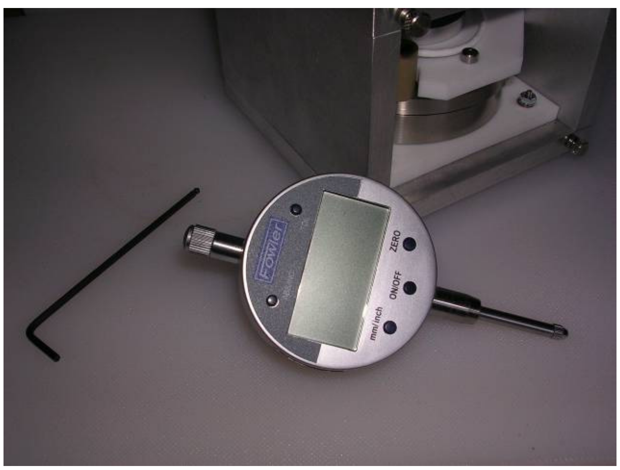

Figure 3
Digital indicator

Install the digital indicator as shown in Figures 4a and 4b.

Figure 4a

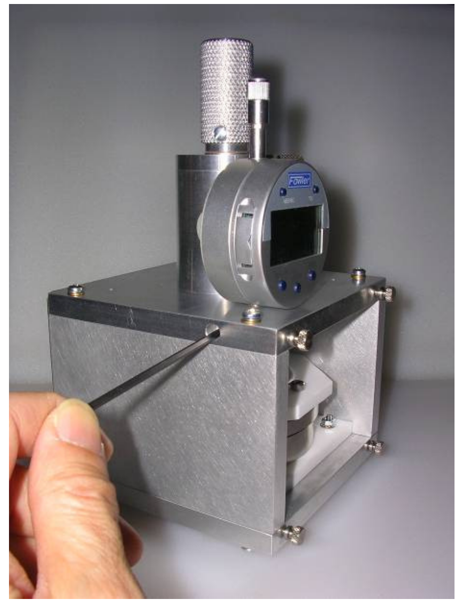

Figure 4b

Figure 4a. Insert the probe tip of the digital indicator through the hole on the top plate of the LT-4203. The probe tip should touch the raised cylindrical piece just below the hole.

Figure 4b. Use the included 3/32" Allen wrench to secure the indicator in place. Insert the Allen wrench through the hole on the left side of the top plate.

NOTE: REMOVE THE INDICATOR BEFORE SUBJECTING THE TEST CELL TO ELEVATED TEMPERATURES. EXPOSURE TO HIGH TEMPERATURES WILL DAMAGE THE INDICATOR.

The indicator may be removed by loosening the set screw and lifting the indicator from its mounting hole.

CONNECTING THE LT-4203 TEST FIXTURE TO THE LT-451 DIELECTRIC CURE MONITOR

The connections from the LT-4203 Test Fixture to the LT-451 Dielectric Cure Monitor are shown in Figure 5a, 5b, 5c and 5d. The LT-4203 has a BNC coaxial cable for the excitation signal and a triaxial cable for the response signal. These two cables connect to a transition box which routes the excitation and response signals into a single LT-451 extension cable. The LT-451 extension cable then plugs into the desired dielectric channel on the rear panel of the LT-451.

Note that the LT-451 extension cable has a banana plug at both ends connected to the cable shield/conduit. These banana plugs connect the LT-451 chassis to the LT-4203 Test Fixture and are necessary to ground LT-4203 Faraday cage for proper operation and shielding.

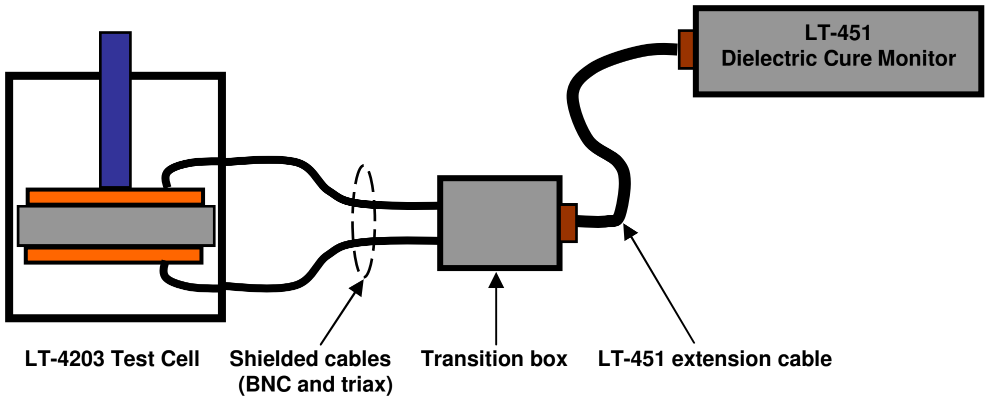

Figure 5a
Connections from the LT-4203 Test Fixture to the LT-451 instrument

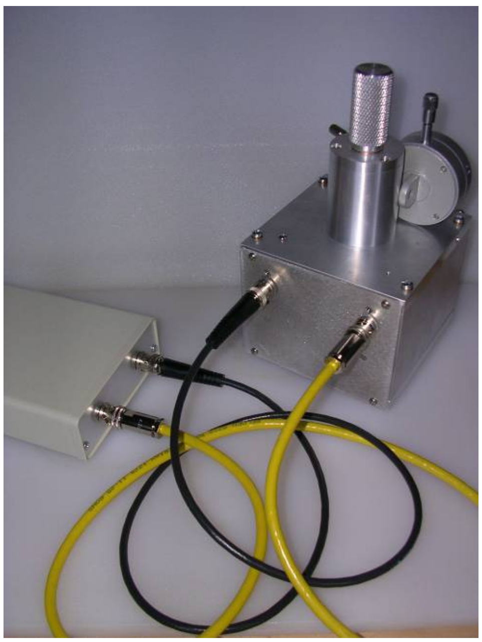

Figure 5b
Cable connections from LT-4203 Test Fixture to transition box

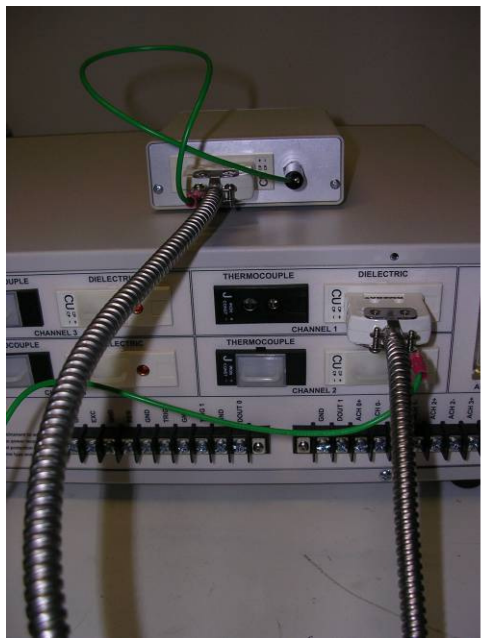

Figure 5c
Ground connections from LT-451 extension cable to transition box

The cable connections are as follows:

a. Plug yellow triax cable into LT-4203 triax bulkhead connector (Figure 5b).

b. Plug black BNC cable into LT-4203 BNC bulkhead connector (Figure 5b).

c. Plug yellow triax cable into transition box bulkhead connector (Figure 5b).

d. Plug black BNC cable into transition box bulkhead connector (Figure 5b).

e. Plug LT-451 extension cable into transition box three-terminal connector (Figure 5c).

f. Insert LT-451 extension cable ground plug into transition box jack (Figure 5c).

g. Plug LT-451 extension cable into LT-451 three-terminal connector (Figure 5d).

f. Insert LT-451 extension cable ground plug into LT-451 ground jack (Figure 5d).

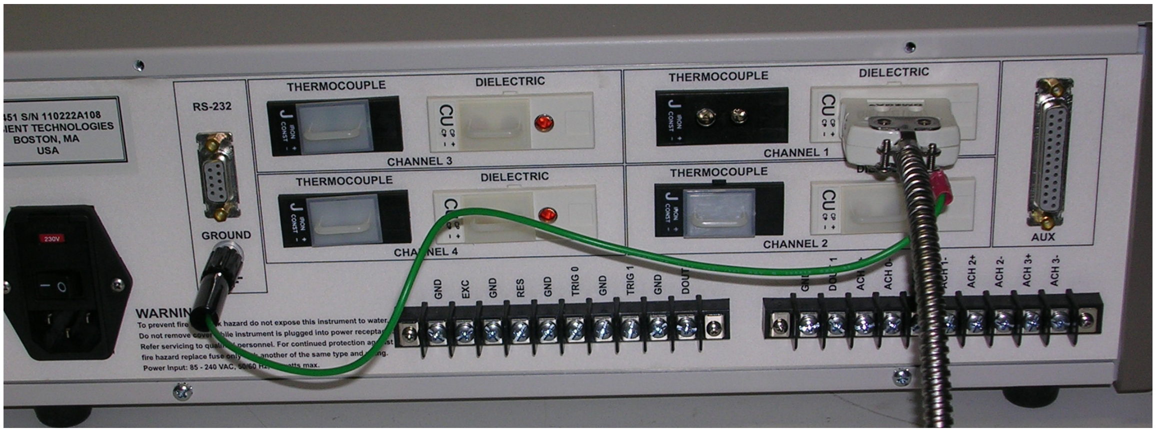

Figure 5d
Ground connection from LT-451 extension cable to LT-451 chassis

CONNECTING THE LT-4203 TEST FIXTURE TO A GENERIC LCR METER

The connection from the LT-4203 Test Fixture to a generic LCR (Inductance-Capacitance-Resistance) meter is shown in Figure 6. The LT-4203 has a BNC coaxial cable for the excitation signal and a triaxial cable for the response signal. The BNC cable must connect to the excitation output of the LCR meter. The triaxial cable must connect to the response input of the LCR meter. Typically the LCR meter input is a BNC and the user must provide a means of making the transition from a triax connector to a BNC connector.

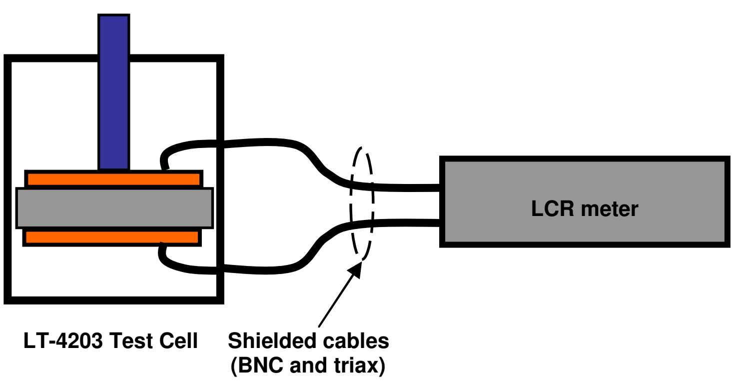

Figure 6
Typical connection from the LT-4203 Test Fixture to an LCR meter

The guard electrode of the LT-4203 is connected to the internal (not outermost) shield of the triaxial cable as shown in Figure 7. Many LCR meters use a virtual ground input, and therefore simply ground the guard electrode of dielectric test cells through the shield of the response BNC connector. For an LCR meter with this configuration, the user must connect the internal shield of the LT-4203 triaxial cable to the response BNC ground.

Upon request Lambient Technologies can modify the LT-4203 connectors or provide appropriate transition boxes for connection to specific LCR meters.

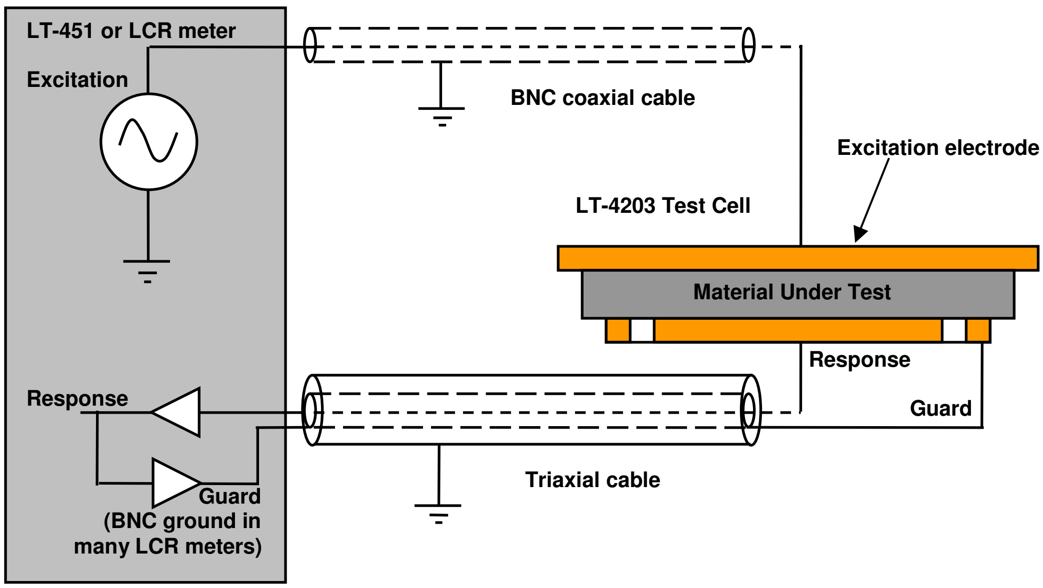

Figure 7
Typical excitation and response cabling to LT-4203 Test Fixture

DETERMINING THE BASE CAPACITANCE (PARASITIC CABLE CAPACITANCE) OF THE LT-4203

The base capacitance C_{BASE} , also known as the parasitic or cable capacitance, must be determined for accurate measurements of the capacitance between the electrodes. This base capacitance tends to be constant for a particular configuration of the LT-4203 Test Fixture, cabling and instrumentation, but it does depend on the length and type of cabling, and the input characteristics of the instrument.

The base capacitance appears in parallel with the capacitance between the electrodes of the test cell, and its effect may be removed by simple subtraction from the raw measurement as shown below:

$$\mathbf{C_{ELECTRODE} = C_{MEASUREMENT} - C_{BASE}}$$

The capacitance between the electrodes, $C_{ELECTRODE,}$ represents the true capacitance of the measurement, whether with or without the Material Under Test, and is the basis for calculating dielectric properties.

Following is the recommended procedure for determining the base capacitance:

1. Adjust the electrodes of the LT-4203 until they contact each other.
2. Zero the digital indicator by pressing the “ZERO” button.
3. Adjust the electrodes of the LT-4203 until the indicator reads 1.00 mm.
4. Measure the capacitance $C_{MEAS\ 1\ mm}$ in air with electrode separation of 1.00 mm.
5. Adjust the electrodes of the LT-4203 until the indicator reads 5.00 mm.
6. Measure the capacitance $C_{MEAS\ 5\ mm}$ in air with electrode separation of 5.00 mm.
7. Calculate ideal capacitance between electrodes. Electrode diameter is 6.00 cm, therefore the capacitance between the electrodes is:

$$\mathbf{C_{ELECTRODE} = \varepsilon_0 * A / D}$$

Where:
$\varepsilon_0 = 8.86 \times 10^{-14}$ F/cm
$A = \pi * (3.00\ \text{cm})^2 = 28.27\ \text{cm}^2$
D = separation between electrodes

Therefore:
$C_{ELECTRODE\ 1\ mm} = 25.05$ pF (calculated for 1 mm separation)
$C_{ELECTRODE\ 5\ mm} = 5.01$ pF (calculated for 5 mm separation)

8. Calculate base capacitance at 1 mm and 5 mm:

$$C_{BASE\ 1\ mm} = C_{MEAS\ 1\ mm} - C_{ELECTRODE\ 1\ mm}$$

$$C_{BASE\ 5\ mm} = C_{MEAS\ 5\ mm} - C_{ELECTRODE\ 5\ mm}$$

9. Calculate average base capacitance:

$$C_{BASE} = (C_{BASE\ 1\ mm} + C_{BASE\ 5\ mm}) / 2$$

10. Example:

$C_{ELECTRODE\ 1\ mm} = 25.05$ pF (calculated air capacitance for D = 1 mm)
$C_{ELECTRODE\ 5\ mm} = 5.01$ pF (calculated air capacitance for D = 5 mm)
$C_{MEAS\ 1\ mm} = 40.4$ pF (measured air capacitance for D = 1 mm)
$C_{MEAS\ 5\ mm} = 20.1$ pF (measured air capacitance for D = 5 mm)

$$C_{BASE\ 1\ mm} = C_{MEAS\ 1\ mm} - C_{ELECTRODE\ 1\ mm} = 15.35\ \text{pF}$$

$$C_{BASE\ 5\ mm} = C_{MEAS\ 5\ mm} - C_{ELECTRODE\ 5\ mm} = 15.09\ \text{pF}$$

$$C_{BASE} = (C_{BASE\ 1\ mm} + C_{BASE\ 5\ mm}) / 2 = 15.22\ \text{pF}$$

PARALLEL PLATE MEASUREMENTS

Dielectric instrumentation measures electrical properties of the Material Under Test (MUT) between a pair of electrodes, which can be modeled as a conductance in parallel with a capacitance, as shown in Figure 8.

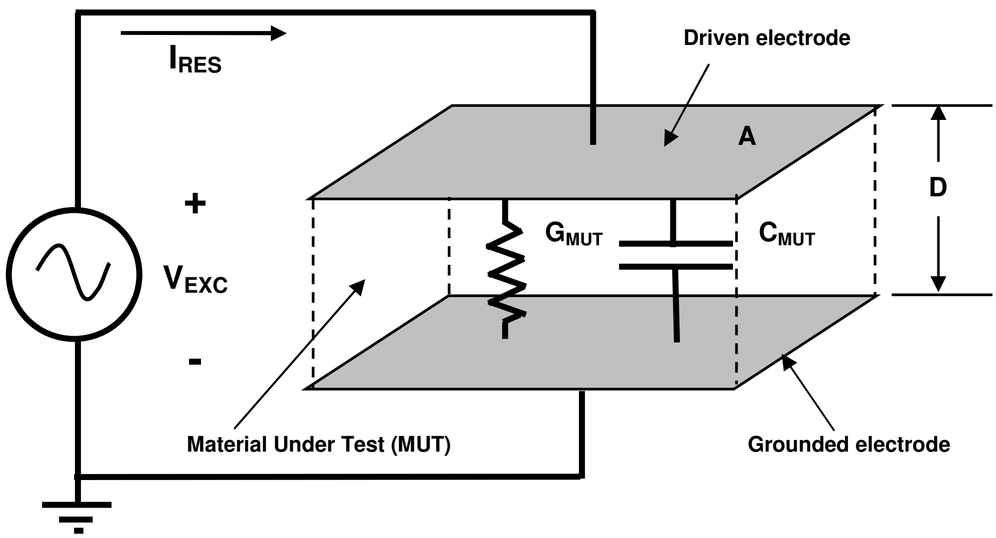

Figure 8
Electrical model of dielectric Material Under Test

The raw measurements at a given frequency f are:

G_{MUT} = conductance (ohms^{-1})
C_{MUT} = capacitance (farads)

With the known quantities of:

$\omega = 2\pi f$
$\varepsilon_0 = 8.86 \times 10^{-14}$ F/cm
A/D = ratio of area to distance for electrodes

then it is possible to calculate the resistance:

(eq. 1)	$\mathbf{R_{MUT} = 1/G_{MUT}}$	(resistance)

and the following material properties:

(eq. 2)	$\boldsymbol{\rho = R_{MUT} * A/D}$	(resistivity or ion viscosity)
(eq. 3)	$\boldsymbol{\sigma' = G_{MUT} / (\varepsilon_o * A/D)}$	(relative conductivity)
(eq. 4)	$\boldsymbol{\varepsilon' = C_{MUT} / (\varepsilon_o * A/D)}$	(relative permittivity)
(eq. 5)	$\boldsymbol{\varepsilon'' = \sigma' / \omega}$	(loss factor)

Dissipation, or $\tan\delta$, at measurement frequency f is the ratio of a material's relative loss to its relative permittivity, and is given by the relationship:

(eq. 6) $$\tan\delta = \varepsilon'' / \varepsilon' = 1 / (\omega\, C_{MUT}\, R_{MUT})$$

Dissipation can be measured in a test cell. In the case of a solid material which can be fabricated as a laminate or a panel, a parallel plate electrode configuration is often used. The guarded parallel plate electrodes of the LT-4203 are diagrammed below in Figure 9.

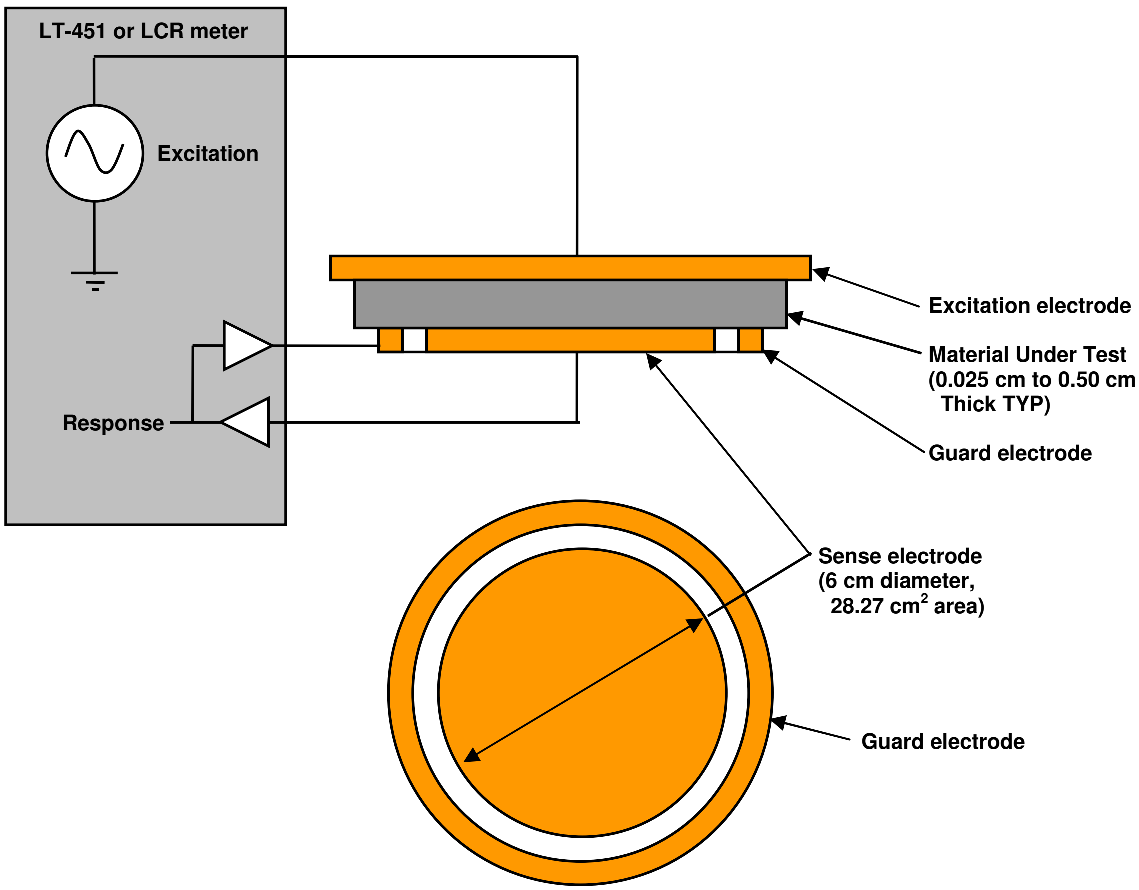

Figure 9
Diagram of LT-4203 guarded parallel plate configuration

For the configuration and electrode dimensions of Figure 9, the air capacitance of the test cell, and the capacitance when filled with a material of relative permittivity $\varepsilon' = 4.0$ (typical for polyimide-glass composites) are listed below in Table 1:

Table 1

Parameters of Example Parallel Plate Configuration

Electrode Separation D (cm)	A/D Ratio (cm)	Air Capacitance (ε' = 1.0)	Material Capacitance (ε' = 4.0)
0.025	1130	100 pF	400 pF
0.25	113.0	10.0 pF	40.0 pF

The Lambient Technologies LT-451 uses the floating electrode method of dielectric measurement, which allows the determination of very high resistances with reduced noise at low frequencies (Ref. Lambient Technologies AN 3—Dielectric Measurement Techniques).

Given the definition of tanδ (eq. 6), the maximum resistance which an instrument can measure, and the material capacitance, it is possible to calculate the smallest dissipation which the instrument can measure at a given frequency. Nominal performance limits of the Lambient Technologies LT-451 are shown in Table 2:

Table 2
LT-451 Nominal Performance Limits

Frequency Range	0.001 Hz to 100 Khz
Optimal Capacitance Range	~20 pF to ~2000 pF
Optimal Resistance Range	~1 KΩ to ~100,000 MΩ

The results for the LT-451 are shown in Table 2 for a frequency of 60 Hz, commonly used because of interest in determining dielectric loss at AC mains frequency. The details for the calculations supporting these results are beyond the scope of this document, but may be obtained from Lambient Technologies upon request.

Table 2
Comparison of Minimum Measurable tanδ at 60 Hz

Material Capacitance	LT-451 Max R_P	LT-451 Min tanδ
30 pF	1000 MΩ	0.09
100 pF	300 MΩ	0.09
300 pF	100 MΩ	0.09
1000 pF	20 MΩ	0.13

Note that to achieve a capacitance of 1000 pF for the LT-4203 Parallel Plate Test Fixture, the film must be 0.017 cm (< 0.007”) thick. While use of such thin films is possible and routine, air gaps can cause inaccuracies; in this case techniques which account for contributions due to air gaps should be used.

CONTACTING ELECTRODE MEASUREMENTS

The contacting electrode method requires only one measurement with the electrodes in direct contact with the MUT as shown in Figure 10. The surface of the MUT must be flat to prevent an air gap between the sample and the electrodes, which can cause a measurement error. The MUT should also be incompressible so the separation between the electrodes is the same as the true thickness of the sample.

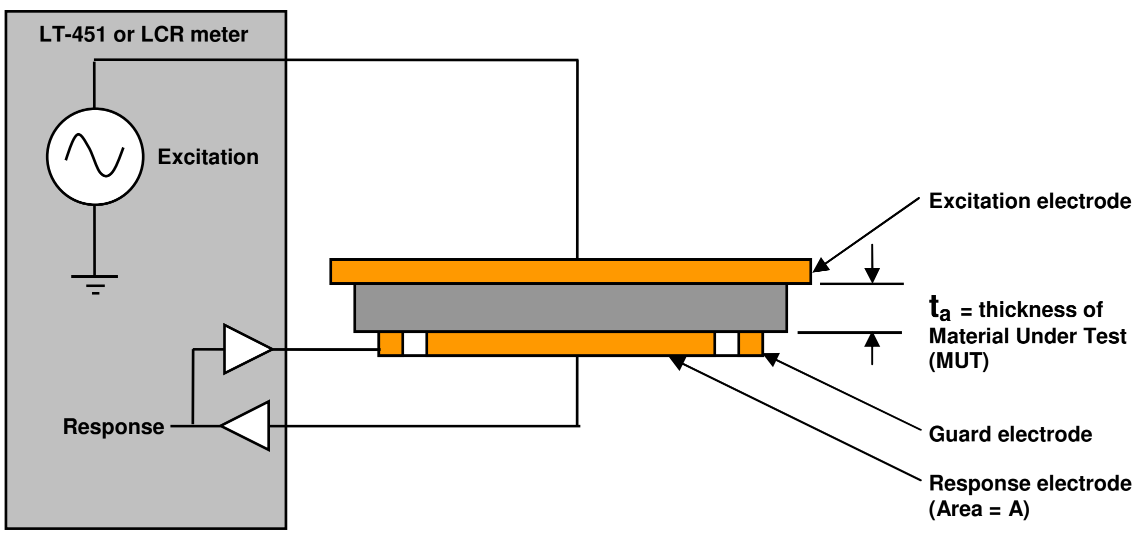

Figure 10
Configuration for contacting electrode measurements

Dielectric properties at frequency of measurement f are calculated below:

(eq. 7)	$\varepsilon' = C_P / (\varepsilon_o * A / t_a)$	(relative permittivity)
(eq. 8)	$\tan\delta = \varepsilon'' / \varepsilon' = 1 / (\omega C_P R_P)$	(dissipation)
(eq. 9)	$\varepsilon'' = \varepsilon' * \tan\delta$	(loss factor)

Where:
$\omega = 2\pi * f$
$\varepsilon_0 = 8.86 \times 10^{-14}$ F/cm
C_P = Capacitance of measurement
R_P = Resistance of measurement

NON-CONTACTING ELECTRODE MEASUREMENTS

The non-contacting electrode method can obtain accurate results for dielectric properties in the presence of an air gap, but requires two measurements. One measurement determines the capacitance and dissipation of the test fixture at a known separation with only air between the electrodes, as shown in Figure 11a. The other measurement determines the capacitance and dissipation at the same separation with the sample inserted between the electrodes, as shown in Figure 11b. For this method the air gap and the compressibility of the MUT do not affect the results.

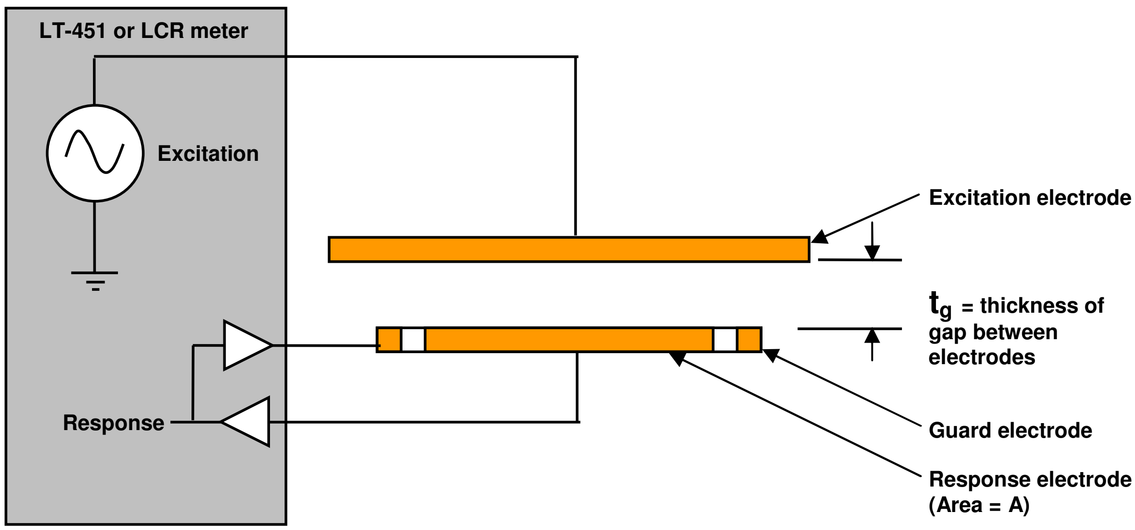

Figure 11a
Non-contacting electrode measurement with air only between electrodes (First measurement)

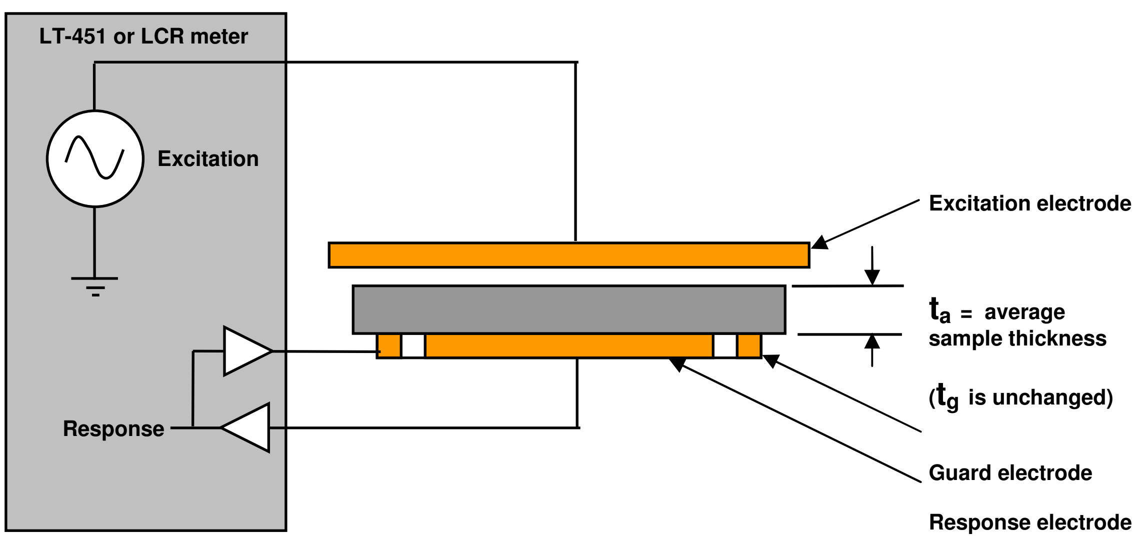

Figure 11b
Non-contacting electrode measurement with sample between electrodes (Second measurement)

For low dissipation the dielectric properties at frequency of measurement, f, are calculated below:

For $(\tan\delta)^2 << 1$

(eq. 10) $\varepsilon' = 1 \;/\; [\,1 - (\,a * b\,)\,]$ (relative permittivity)

(eq. 11) $\tan\delta = \tan\delta_{P2} + [\,\varepsilon' * c * d\,]$ (dissipation)

(eq. 12) $\varepsilon'' = \varepsilon' * \tan\delta$ (loss factor)

Where:

$\omega = 2\pi * f$

C_{P1} = Capacitance (F) without MUT inserted (Fig. 11a)

R_{P1} = Resistance (Ω) without MUT inserted (Fig. 11a)

$\tan\delta_{P1}$ = Dissipation without MUT inserted (Fig. 11a) $= 1 / (\omega\, C_{P1}\, R_{P1})$

C_{P2} = Capacitance (F) with MUT inserted (Fig. 11b)

R_{P2} = Resistance (Ω) with MUT inserted (Fig. 11b)

$\tan\delta_{P2}$ = Dissipation with MUT inserted (Fig. 11b) $= 1 / (\omega\, C_{P2}\, R_{P2})$

t_g = Separation (m) between response and excitation electrodes

t_a = Average sample thickness (m)

$a = 1 - (\,C_{P1} / C_{P2}\,)$

$b = t_g / t_a$

$c = \tan\delta_{P2} - \tan\delta_{P1}$

$d = (\,t_g / t_a\,) - 1$

Results for the non-contacting electrode measurements can be as accurate as the measurements of electrode separation and sample thickness. But for situations where the air gap is a large fraction of the sample thickness, the calculations for relative permittivity, ε', and dissipation, tanδ, are very sensitive to uncertainties in t_g and t_a . Consequently, non-contacting electrode measurements are best used for thicker samples where the air gap can be relatively small.

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